An Approach to the Design of a New System:

Methodology as Applied to the MAGTF Expeditionary Family of Fighting Vehicles (MEFFV)

Methodology Technical Leads:

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Sponsored by:

Office of Naval Research

Naval Surface Warfare Center

22 October 2003

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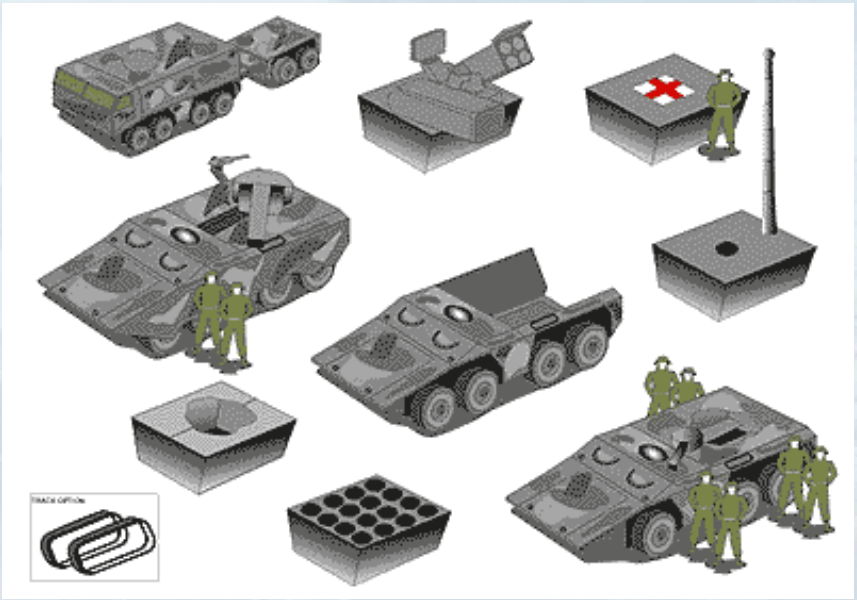
Aerospace Systems Design La

What is MEFFV?

The current fleet of LAV's (Light Armor Vehicles) and M1A1 Common Main Battle Tank's will be 30+ years old in 2015 and 2020, respectively.



This anticipated capability gap will be addressed by a multi-mission family of fighting vehicles to conduct reconnaissance, shaping, and decisive operations.

Intended to extend the operational reach of the Marine Air Ground Task Force (MAGTF) [illegible] of conflict.

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MEFFV Specifics

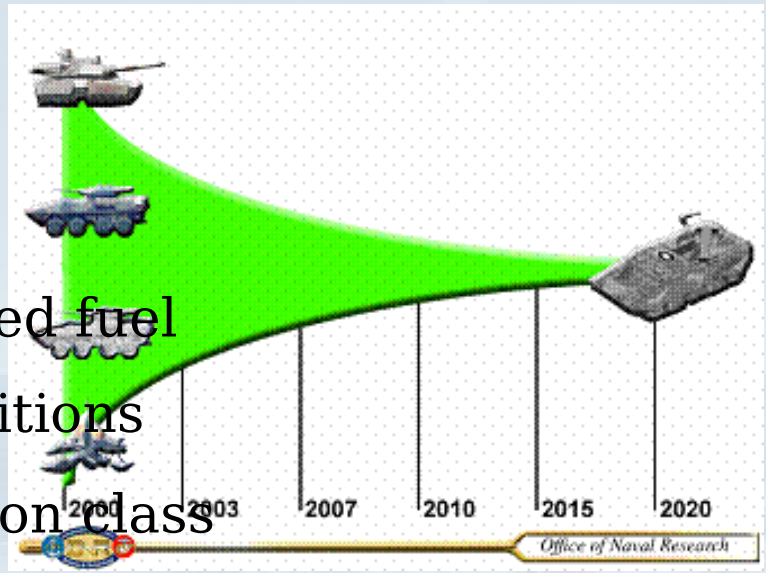
- Designed for the 2020 timeframe

-Will combine high technology with maneuver warfare

- Less dependent on petroleum-based fuel

- Less reliant on carbon-based munitions

- Vehicle platforms in the 10 to 30 ton class



-Will surpass legacy vehicles in survivability, sustainability, deployability, and employment

-Will utilize advanced technologies to increase lethality, survivability, and situational awareness while simultaneously reducing size, weight, cube, and logistical requirements

- Still in concept and development stage ⇨ many “soft” requirements

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Customer Wants and Needs

Contract performed for the Naval Surface Warfare Center (NSWC) and the Office of Naval Research (ONR). Technical customer was the Marine Corps Warfighter.

- Customer wants us to "***start from the beginning***" in assessing the requirements for MEFFV and the technologies needed
- Customer wants ***resource allocation guidance*** as the MEFFV program moves forward
- Customer wants help ***understanding the Naval Universal Task List*** (NUTL)
- Initial efforts should focus on the MEFFV "Vehicle" but impacts on the composite force are desired
- Customer wants ***cost tracked*** as we proceed; technology development cost, not procurement cost
- Key ***system operational constraints***: deployment footprint, resupply requirements, close-in protection for light vehicles, total power requirement, understanding swim trades

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Bringing Knowledge Forward

This is the timeframe in weapons system acquisition where cost is committed.

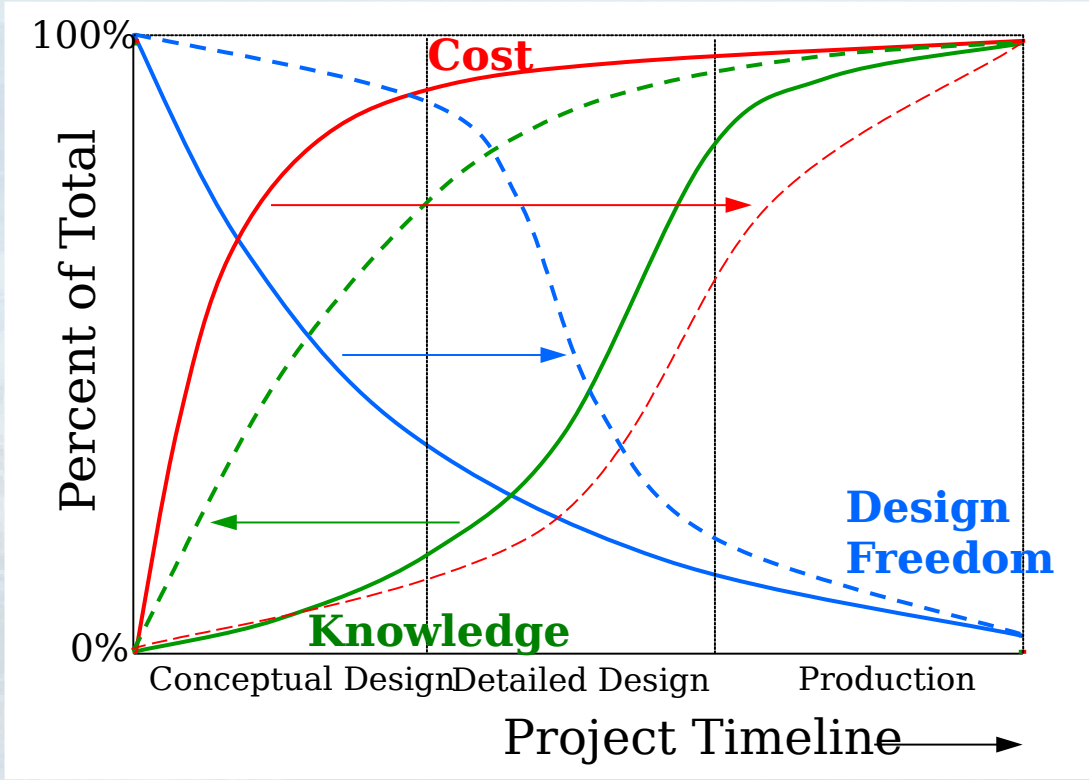
By bringing knowledge forward in the design of a highly complex and integrated system, the following results can be obtained:

-Lower overall cost

-Better design

-Smarter commitment of resources

-Keeps design freedom open longer



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The Approach

Task 1- Qualitative Analysis

Goal: Complete a Quality Function Deployment (QFD) Based MEFFV Requirements Analysis

Results: Group will have created a "living" MEFFV requirements analysis that allows for sensitivity analysis and updates

- Focus attention on most critical design drivers
- Identification of top level trades that need to be cons
- Identify potential conflicts between multiple technical capabilities

Task 2- Qualitative and Quantitative Analysis

Goal: Introduce and Demonstrate a Quantitative ***Survivability and Propulsion Pilot Study***

Results: Group will have understanding of how presented methods and analysis techniques may be used in subsequent MEFFV tasks and analysis

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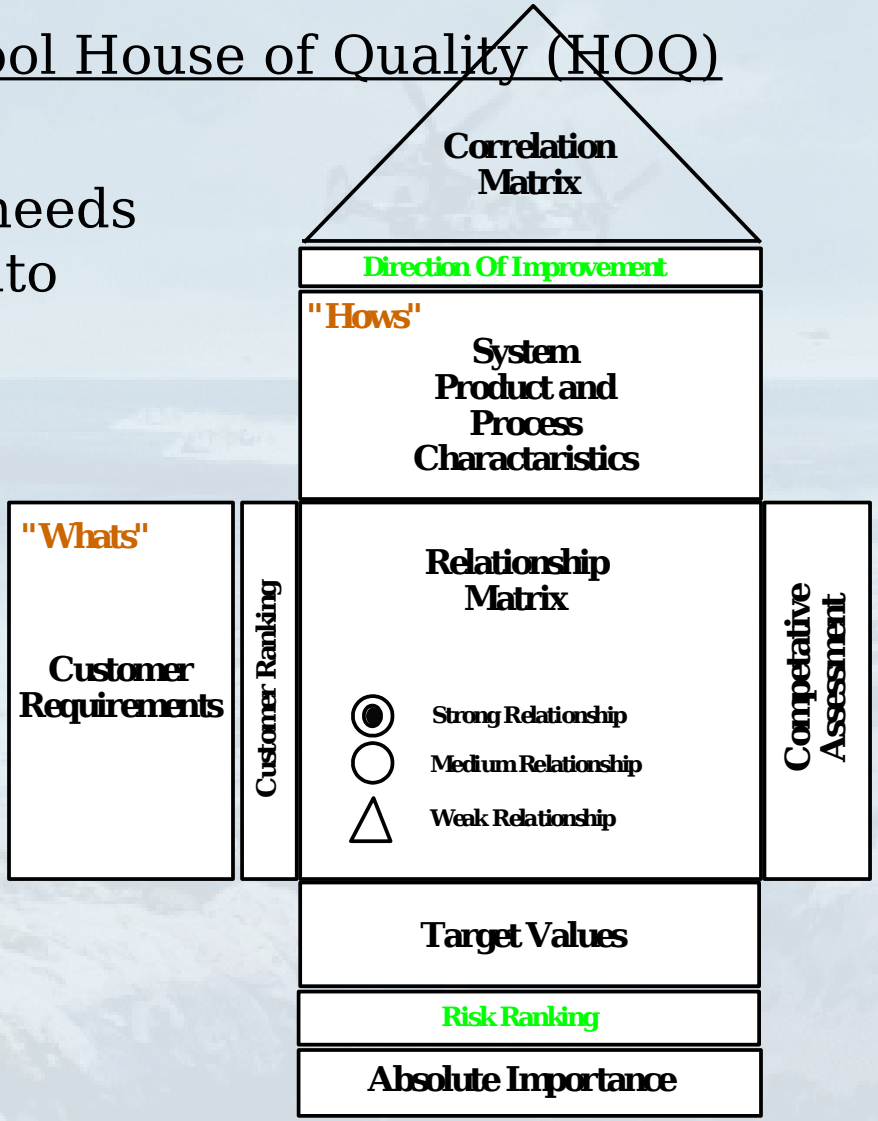
The Tools-QFD Analysis

Quality Function Deployment tool House of Quality (HOQ)

- A way to translate customer needs and requirements (“what’s”) into prioritized engineering targets (“how’s”)
- Is completed by a brainstorming team that must include the customer
- Provides insight into system relationships
- The process is just as important, often more so, than the result



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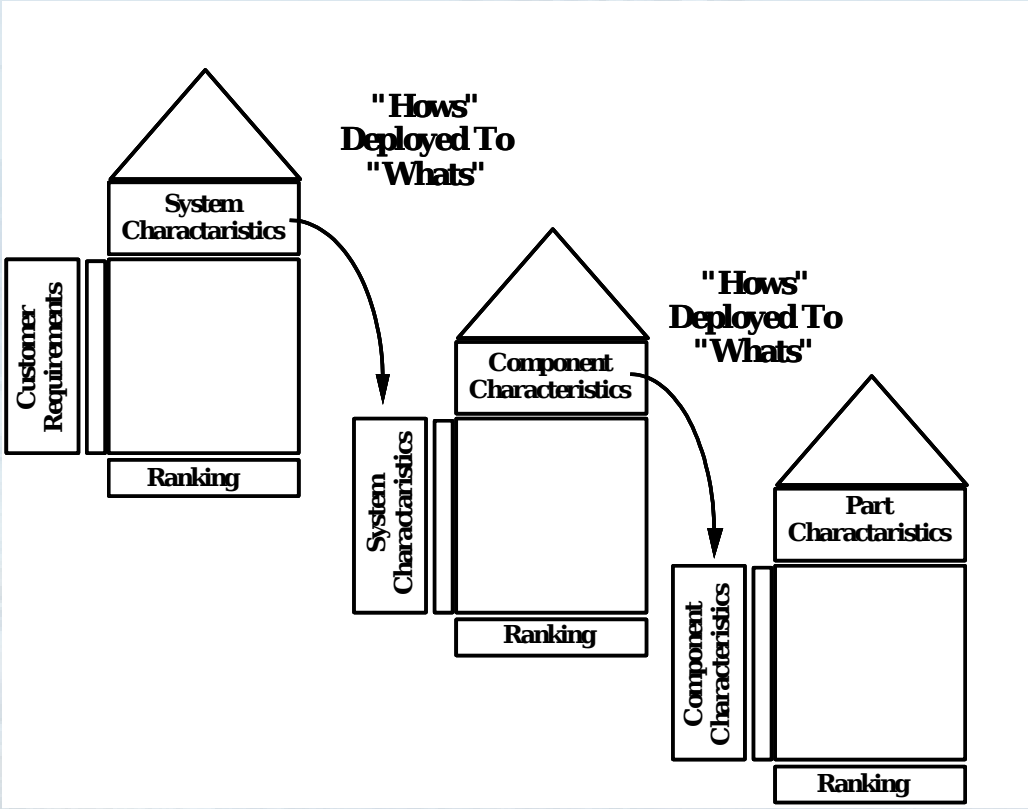
The Tools- QFD Analysis

House of Quality Phase Progression

Provides a useful way of "zooming in" on certain key areas of the system, allowing a more detailed analysis.

Especially useful in a System of Systems formulation



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The Tools-Morphological Matrix

Each row lists a product design feature.
Each column lists design choices available.

Example: Supersonic Transp

One choice from each column defines one baseline concept to explore

"tool that provides a structured search and combination of concepts in product design"
(Otto and Wood, 2001)

	Alternatives			
Configuration	Vehicle	Wing/Tail	Wing/Canard	Wing, Tail, Canard
	Fuselage	Cylindrical	Area Ruled	Oval
	Pilot Visability	Synthetic Vision	Conventional	Droop Nose
Mission	Range (nmi)	5000	6000	6500
	Passengers	250	300	320
	Mach Number	2	2.2	2.4
Propulsion	Type	MFTF	Turbine Bypass	Mid Tandem Fan
	Combustor	Conventional	RQL	LPP
	Nozzle	Conventional	Internal Flow Alteration	Mixed Ejector
Aero.	Low Speed	Flaps	Flaps and Slats	Circulation Control
	High Speed	Conventional	NFLC	Active Control
Structures	Materials	Aluminum	Titanium	Composite
	Process	Integrally Stiffened	Spanwise Stiffened	Monocoque

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The Tools-Pugh Matrix

Allows a comparison of several design concepts against an established datum, and ranks those concepts with respect to design criteria

	Candidate Concepts					
Criteria	1	2	3	4	5	Datum
A	+	0	+	+	-	0
B	0	+	-	+	0	0
C	-	-	0	+	+	0
D	+	-	-	+	0	0
E	-	+	+	-	-	0
F	-	+	0	+	-	0
Σ +	2	3	2	5	1	0
Σ -	3	2	2	2	3	0
Σ S's or 0's	0	1	2	0	1	6
Total	**-1**	**1**	**0**	**3**	**-2**	**0**

0 neutral
\+ better than
\- worse than

"best" concept compared to datum

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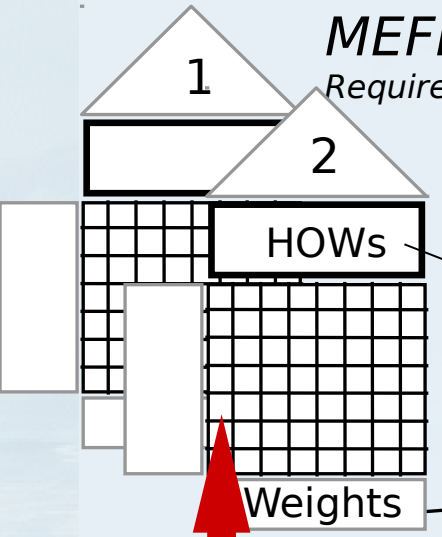
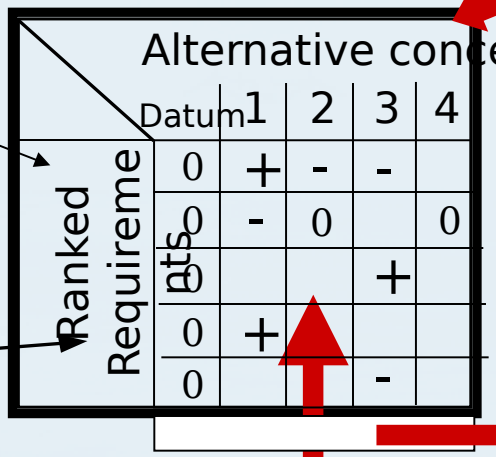
Task 1- Qualitative Approach



MEFFV QFD

Requirements Analysis



Morphological Matrix

Tech. Concept Alternative Synthes

System Capability, Design Implication	Tech Options List	1- Low Risk	2- Med Risk	3- High Risk
Avoid Detection	Signature Mngt	Obscurants	Signature Mgt	Stealth Materials
	Obscurants			
	Stealth materials			
Avoid Acquisition	E-O Warning	Laser Warning		E-O Warning
	Laser Warning			
Avoid Hit	Missile Warning	Missile Warning	Guidance Jamming	Active Protection
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	Active Protection			
Avoid Penetration	Adv Passive Armor (APM)	APM EC & CH	ARM SA & ERA	APM NC & ARM EMA
	Adv Reactive Armor (ARM)			

One Concept Alter

MEFFV Pugh Evaluation Matrix

MADM*

Best MEFFV Alternatives

Subjective Evaluation (through expert opinion, surveys, etc.)

*Multi-Attribute Decision-Making

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The Tools-RSM and Prediction Profiles

Response Surface Methodology (RSM) is a metamodeling technique

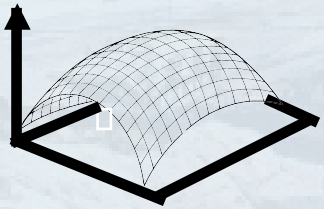
Metamodel- in essence, a “model of a model”, formulated to capture most, if not all, of the significant effects of the more complex model it is emulating.

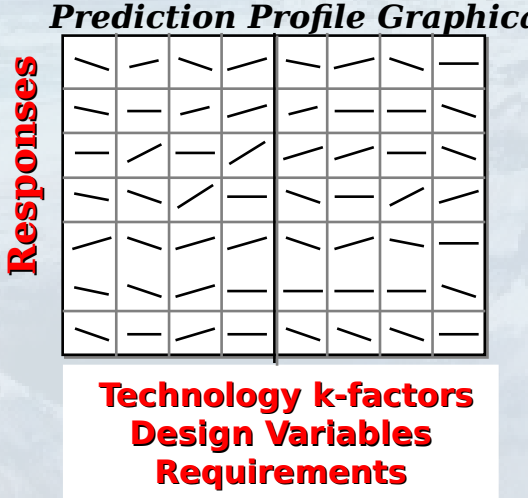
A computationally efficient way to explore and analyze the design space. Once the initial computational investment is made, the resulting metamodels may be used to conduct trade studies without rerunning the simulation.

Starts to bring quantitative knowledge forward in the design process, enhancing design freedom and delaying cost commitments

Design of Experiments (DoE) is used to determine the settings of the variables for each experimental case (or each computational execution of the code)

$$R = b_o + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} x_i x_j$$





b_i are regression coefficients for the first degree terms
b_{ii} are coefficients for the pure quadratic terms
b_{ij} are the coefficients for the cross-product terms

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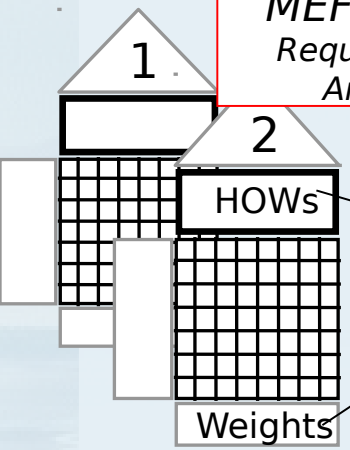
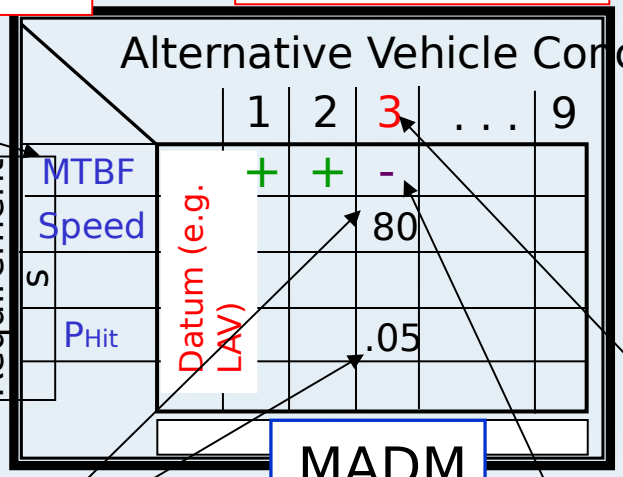
Tailored MEFFV Process Roadmap



MEFFV QFD
Requirements Analysis

MEFFV Pugh Evaluation Matrix



Morphological

Survivability- 3 Alternativ

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	Stealth materials			
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	Guidance Jamming			
	Active Protection			
Avoid Penetration	Adv Passive Armor (APM)	APM EC & CH	ARM SA & ERA	APM NC & ARM EMA
	Adv Reactive Armor (ARM)			

Propulsion- 3 Alternatives

Characteristics	Alternative 1	Alternative 2	Alternative 3
Propulsion Power Source (7 alternatives)	Advanced IC Engine	Gas Turbine Engine	Advanced Lithium-Ion Battery
Generic/Auxiliary Power Source (8 alternatives)	Solar Cells	Hybrid Galvanic/Solar Cells	Advanced Lithium-Ion Battery
Payload/High Power-Need Source (8 alternatives)	Super/UltraCapacitor	Hybrid Galvanic Cell/Cap.	Generator (tapping heat)
Means of Movement (8 alternatives)	Tracked	Wheeled	Wheeled/Tracked
Power Transmission for Propulsion	Electric-Motor	Mechanical-Shaft	
Power Source(s) to Systems	Centralized Energy Conv.	Distributed Power Gen.	
Fuel Type (4 alternatives)	JP-8	Diesel Variant	Natural Gas
Power Conditioning	AC Motors	DC Motors	

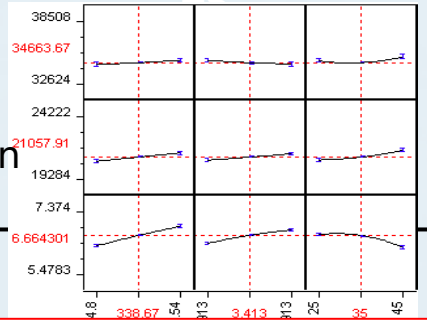
MADM

Best MEFFV Alternativ

Vehicle Synthesis Model

- Size the vehicle/engine and assess performance based on technology requirements

$(P_{req})_{mob}$ $(P_{req})_{surv}$ $(P_{Avail})_{main}$ $(P_{Avail})_{aux}$



Expert Opinion

MEFFV Concept #3 Defined

Modeling & Simulation

- Survivability

RSEs for Tech Analysis & Visualization

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MEFFV QFD Analysis

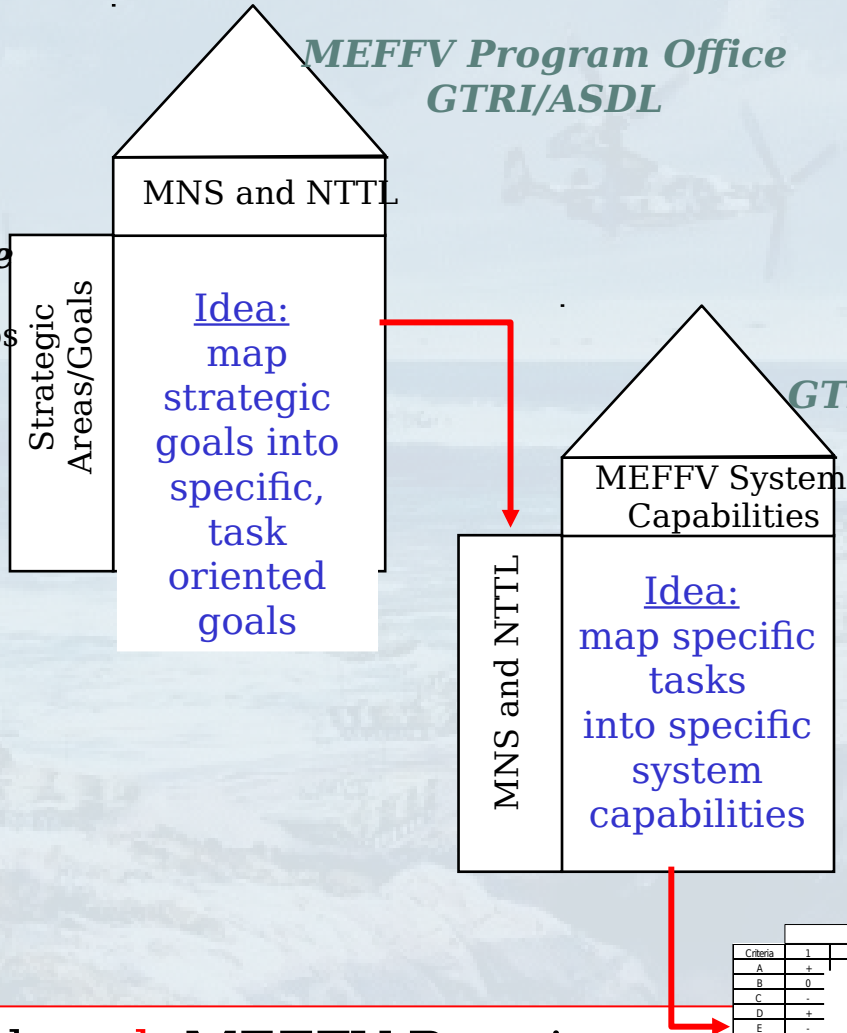
Guiding Documents

Expeditionary Maneuver Warfare
Department of the Navy
Headquarters, Unites States Marine Corps

Mission Need Statement (MNS) *for the MAGTF Expeditionary Family of Fighting Vehicles (MEFFV)*

MEFFV Technical CONOPS
containing the *Naval Tactical Task List (NTTL)2.0*

ONR/BAH Technology Roadmap CD
Broad Overview of Technologies from 2000



Overall, understand and rank MEFFV Requiremen

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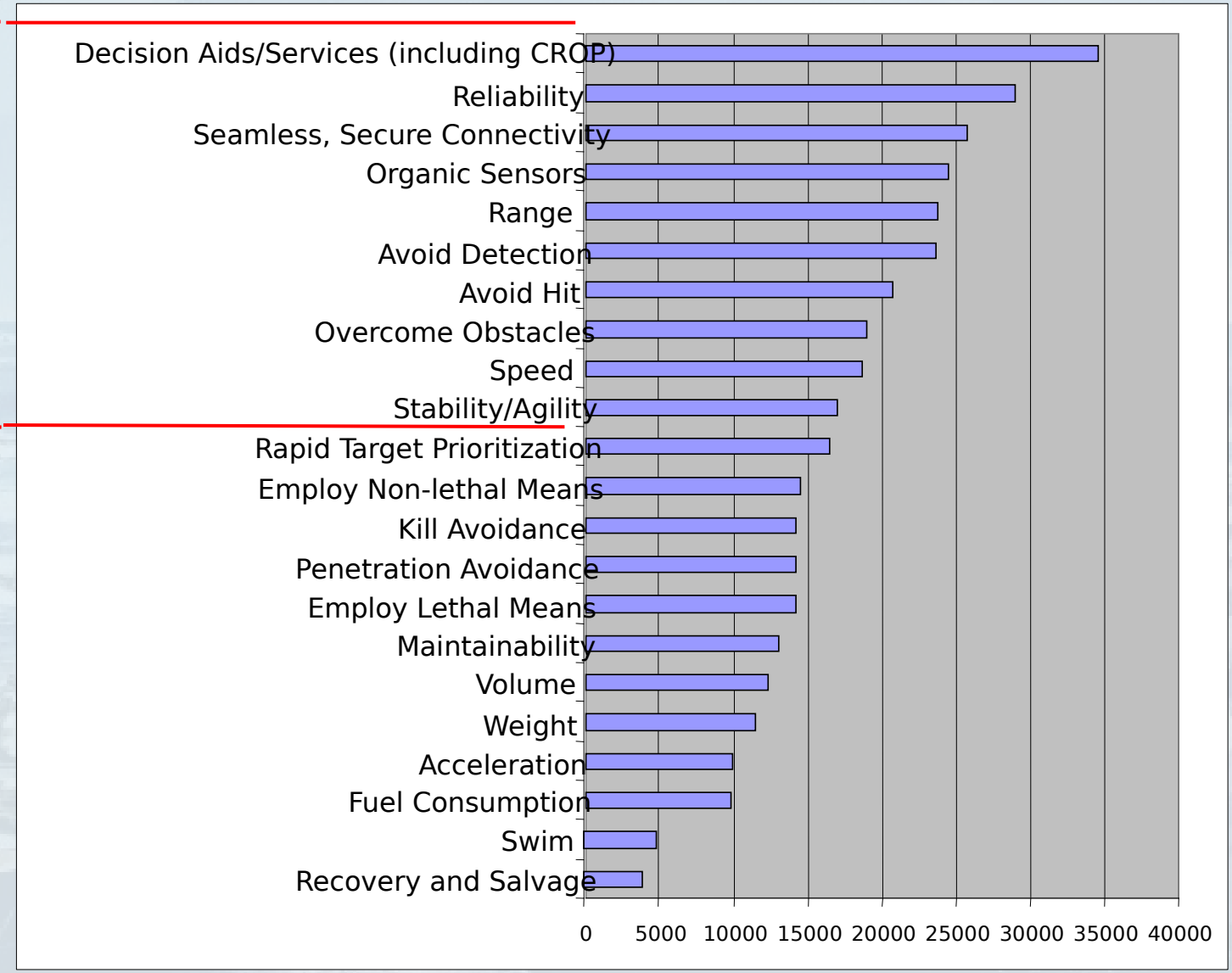
QFD Results- Ranking of All How's

Top 10



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Initial QFD "Take Aways"

- Most Important- QFD provides a "living" communication tool between the warfighter (customer) and the technology development community for the constant assessment and flowdown of requirements
- Initial QFD results indicate that MEFFV capabilities related to C4ISR, Mobility (speed/range), and Survivability are key. Reliability is also highly important, although it is likely that a better understanding of what this means is in order.
- Further use of QFD is advised, most importantly in having the warfighter model alternate missions in HOQ1, for investigation of downstream effects on best concepts

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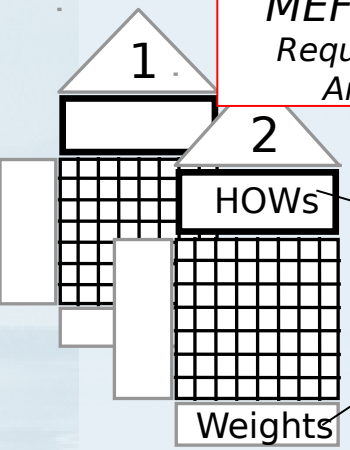
Tailored MEFFV Process Roadmap



MEFFV QFD
Requirements Analysis

MEFFV Pugh Evaluation Matrix

Alternative Vehicle Concepts

	1	2	3	. . .	9
MTBF	+	+	-		
Speed			80		
P_{Hit}			.05		

Datum (e.g. LAV)

Ranked Requirements

Morphological

Survivability- 3 Alternativ

System Capability, Design Implication	Tech Options List	1-Lo	2-Me	3-Hi
Avoid Detection	Signature Mngt	Obscurants	Signature Mgt	Stealth Materials
	Obscurants			
	Stealth materials			
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Propulsion- 3 Alternatives

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Power Source(s) to Systems	Centralized Energy Conv.	Distributed Power Gen.	
Fuel Type (4 alternatives)	JP-8	Diesel Variant	Natural Gas
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MADM

Best MEFFV Alternativ

MEFFV Concept #3 Defined

Vehicle Synthesis Model

• Size the vehicle/engine and assess performance based on technology requirements

$(P_{req})_{mobility}$ $(P_{Avail})_{main}$

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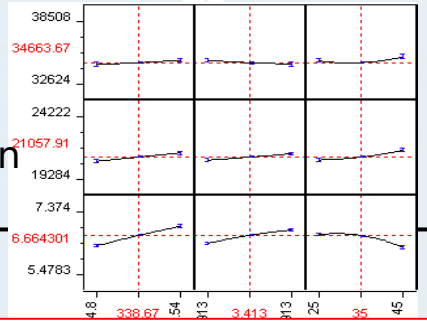

Expert Opinion

Modeling & Simulation

• Survivability

RSEs for Tech Analysis & Visualization

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MEFFV Survivability Morph Matrix

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Description of 9 Matrixed Concepts

Survivability Concepts

S1 Signature management to enable MEFFV to see and shoot first, using low-e coatings, thermal shielding, camouflage patterns, and possible active cooling.

S2 Signature management as above, plus missile warning system with highly accurate direction-of-arrival characteristics, on-board obscurant system

S3 deploying either visible or IR obscurants.

Signature management, missile warning, obscurant system as above, plus Active Protection System (APS) using MWS as first stage cueing device.

Propulsion Concepts

P1 Advanced IC Engine, mechanical shaft torque, advanced heat engine/generator auxiliary power

P2 Hybrid drive system: advanced IC engine and advanced secondary batteries, high torque electric motor, solid oxide fuel cells auxiliary power.

P3 Series/parallel hybrid drive system: solid oxide fuel cells and advanced secondary batteries, electric motor, solid oxide fuel cells auxiliary power.

Three Survivability Concepts and three Propulsion concepts produce 9 possible

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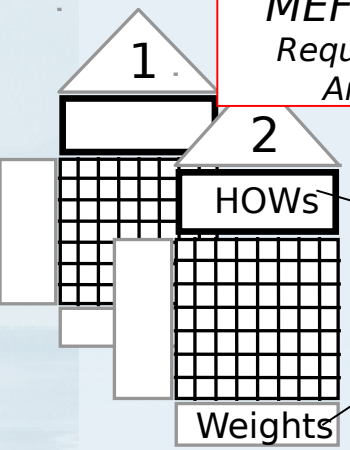

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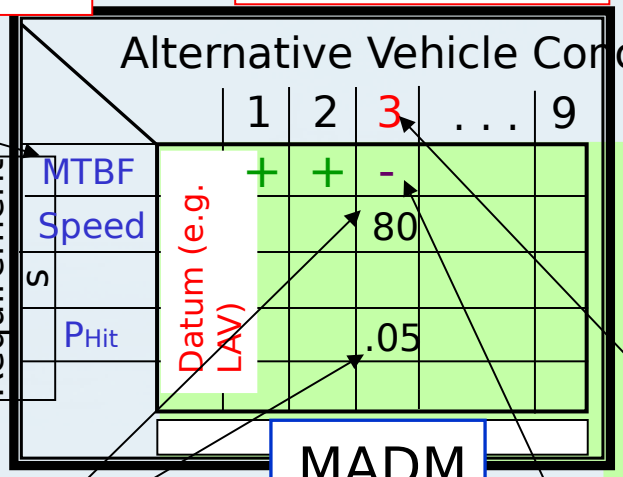

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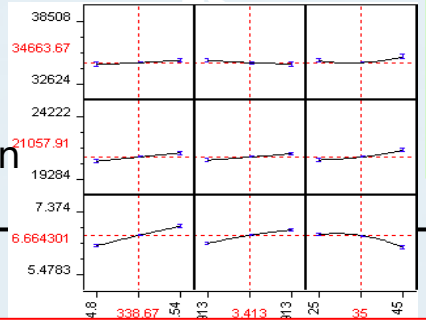

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Pugh Matrix: Propulsion/Survivability vs. M1A1

	P1S1		P1S2		P1S3		P2S1		P2S2		P2S3		P3S1		P3S2		P3S3		M1A1
	P1	S1	P1	S2	P1	S3	P2	S1	P2	S2	P2	S3	P3	S1	P3	S2	P3	S3	Datum
Speed	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	0
Range	+	0	+	0	+	0	+	0	+	0	+	0	++	0	++	0	++	0	0
Stability/Agility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acceleration	+	0	+	0	+	0	++	0	++	0	++	0	-	0	-	0	-	0	0
Overcome Obstacles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Swim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Employ Lethal Means	0	0	0	+	0	+	0	0	0	+	0	+	0	0	0	+	0	+	0
Employ Non-lethal Means	0	0	0	+	0	+	0	0	0	+	0	+	0	0	0	+	0	+	0
Rapid Target Prioritization	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Avoid Detection	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Avoid Hit	0	+	0	+	0	++	0	+	0	+	0	++	0	+	0	+	0	++	0
Penetration Avoidance	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Kill Avoidance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NBC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reliability	+	0	+	0	+	-	-	0	-	0	-	-	--	0	--	0	--	-	0
Maintainability	+	0	+	0	+	-	-	0	-	0	-	-	--	0	--	0	--	-	0
Recovery and Salvage	0	0	0	0	0	0	+	0	+	0	+	0	-	0	-	0	-	0	0
Fuel Consumption	+	0	+	0	+	0	+	0	+	0	+	0	++	0	++	0	++	0	0
Weight	+	0	+	0	+	0	-	0	-	0	-	0	--	0	--	0	--	0	0
Volume	+	0	+	0	+	0	-	0	-	0	-	0	--	0	--	0	--	0	0
Organic Sensors	0	0	0	+	0	+	0	0	0	+	0	+	0	0	0	+	0	+	0
Seamless, Secure Connectivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decision Aids Services	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Sum +	12		15		16		10		13		14		9		12		13		0
Sum -	1		1		2		5		5		6		11		11		13		0
Sum 0	33		30		28		32		29		27		32		29		28		0
Pluses - Minuses	**11**		**14**		**14**		**5**		**8**		**8**		**-2**		**1**		**0**		**0**

"best" concepts compared to M1A1

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MEFFV Pugh Matrix "Take Away"

- P1 dominates the rankings. This is the "best" concept when considering the characteristics and capabilities, cost, risk, and benefit.

- The survivability scenarios have very few negative effects, even as the risk level increases (S1 to S3). However, as the risk level increases (moving from P1 to P3), the propulsion scenarios start demonstrating higher negative impacts in some key characteristics.

- These results may be used to envision near term fielding concepts (P1S2) and upgraded out year concepts (P3S3), given that technologies can be brought to bear on the negative impacts.

- Note that direct interaction effects between the Scenario and Propulsion scenarios have not yet been accounted for.

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Tailored MEFFV Process Roadmap

MEFFV QFD
Requirements Analysis

1
2
HOWs
Weights

Ranked Requirements

MEFFV Pugh Evaluation Matrix

Alternative Vehicle Concepts

	1	2	3	. . .	9
MTBF	+	+	-		
Speed			80		
P_{Hit}			.05		

Datum (e.g. LAV)

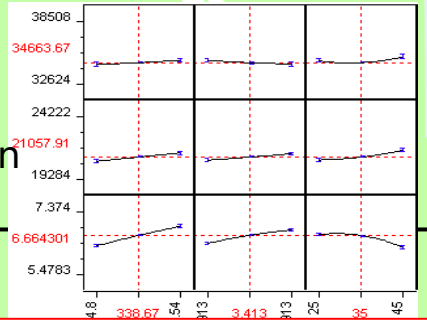
MADM

Best MEFFV Alternativ

Vehicle Synthesis Model

- Size the vehicle/engine and assess performance based on technology requirements

$(P_{req})_{mob}$ $(P_{Avail})_{main}$
$(P_{req})_{surv}$ $(P_{Avail})_{aux}$



Expert Opinion

Morphological

Survivability- 3 Alternativ

System Capability, Design Implication	Tech Options List	1-Lo	2-Me	3-Hi
Avoid Detection	Signature Mngt	Obscurants	Signature Mgt	Stealth Materials
	Obscurants			
	Stealth materials			
Avoid Acquisition	E-O Warning	Laser Warning		E-O Warning
	Laser Warning			
Avoid Hit	Missile Warning	Missile Warning	Guidance Jamming	Active Protection
	Guidance Jamming			
	Active Protection			
Avoid Penetration	AdvPassive Armor (APM)	APM EC & CH	ARM SA & ERA	APM NC & ARM EMA
	AdvReactive Armor (ARM)			

Propulsion- 3 Alternatives

Characteristics	Alternative 1	Alternative 2	Alternative 3
Propulsion Power Source (7 alternatives)	Advanced IC Engine	Gas Turbine Engine	Advanced Lithium-Ion Battery
Generic/Auxiliary Power Source (8 alternatives)	Solar Cells	Hybrid Galvanic/Solar Cells	Advanced Lithium-Ion Battery
Payload/High Power-Need Source (8 alternatives)	Super/UltraCapacitor	Hybrid Galvanic Cell/Cap.	Generator (tapping heat)
Means of Movement (8 alternatives)	Tracked	Wheeled	Wheeled/Tracked
Power Transmission for Propulsion	Electric-Motor	Mechanical-Shaft	
Power Source(s) to Systems	Centralized Energy Conv.	Distributed Power Gen.	
Fuel Type (4 alternatives)	JP-8	Diesel Variant	Natural Gas
Power Conditioning	AC Motors	DC Motors	

MEFFV Concept #3 Defined

Modeling & Simulation

- Survivability

RSEs for Tech Analysis & Visualization

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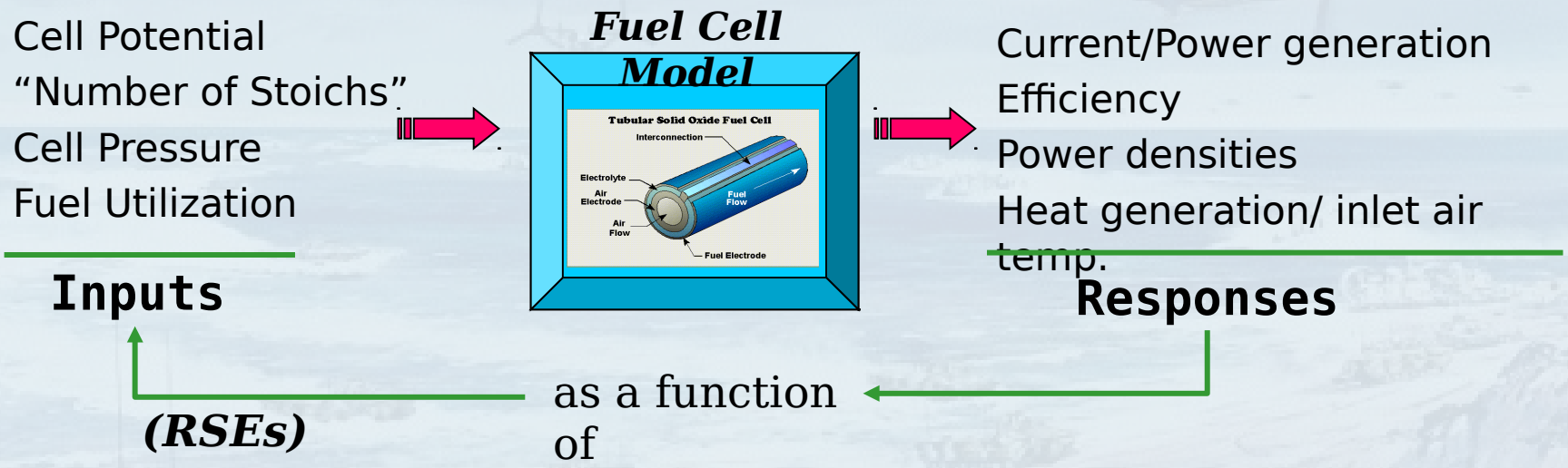
ASDL
Aerospace Systems Design La

Fuel Cell Modeling and RSM

Response Surface Methodology (RSM) was applied to the Fuel Cell technology to create Response Surface Equations (RSEs) that mapped fuel cell modeling responses to code inputs.



The first use of the resulting RSEs is as a debugging tool. By examining the trends, the analyst can ensure there are no errors in the analysis code and/or the regression.

Once the trends are verified, the RSEs can be used to conduct rapid trade studies and optimization, as well as serve as a "living" and extremely rapid representation of the modeling code itself. This allows the analyst to rapidly examine the complete design space without repeated executions of the initial

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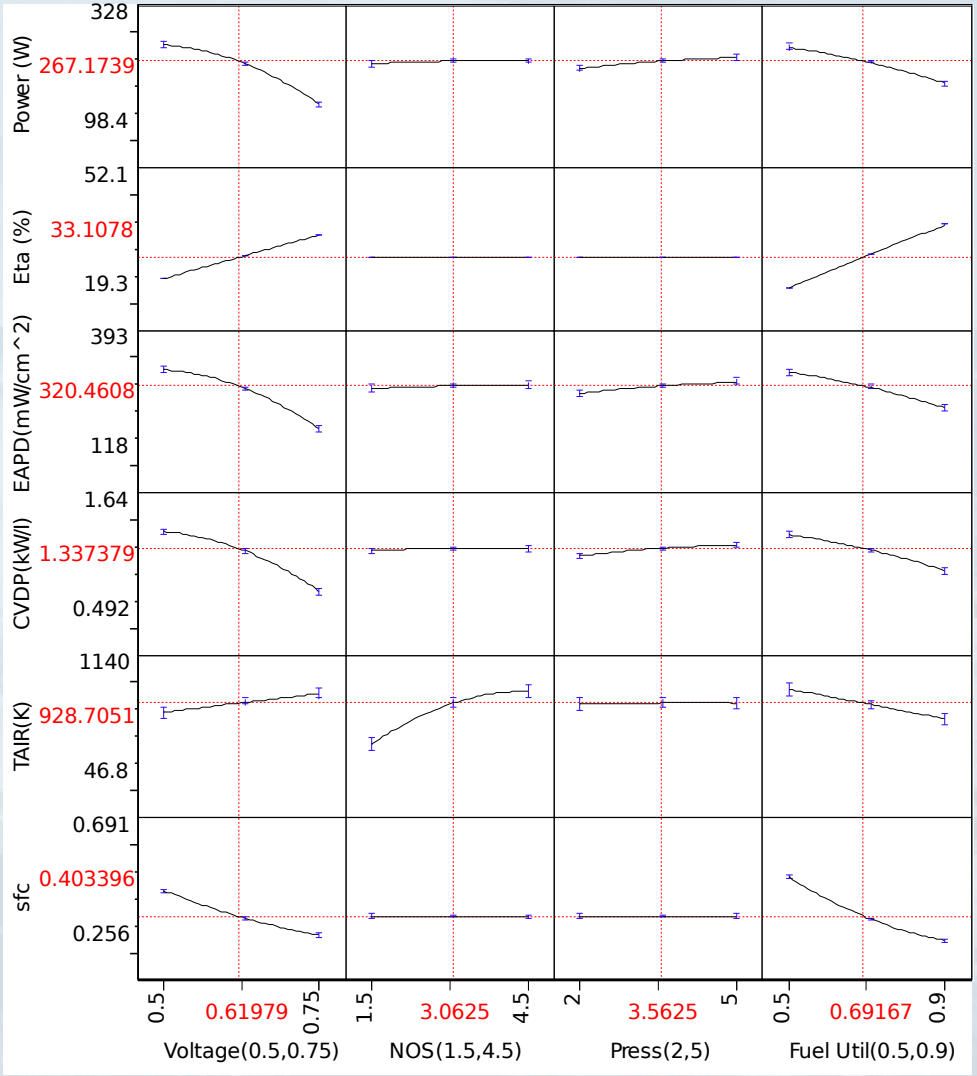
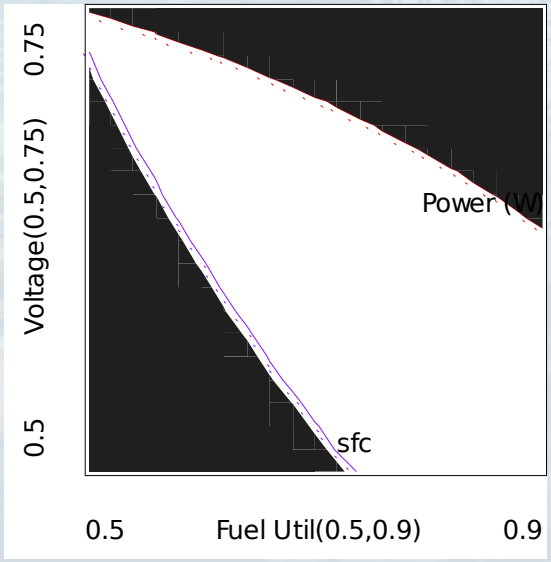
Fuel Cell Modeling

Real-Time Visualization of Constraint Space



Horiz	Vert	Factor	Current X
○	●	Voltage(0.5,0.75)	0.6197917
○	○	NOS(1.5,4.5)	3.0625
○	○	Press(2,5)	3.5625
●	○	Fuel Util(0.5,0.9)	0.6916667

Response	Contou	Current Y	Lo Limit	Hi Limit
Power (W)	213	267.1739	213	.
Eta (%)	.	33.10780	.	.
EAPD(mW/cm^2	.	320.4608	.	.
CVDP(kW/l)	.	1.337378	.	.
TAIR(K)	593.4	928.7051	.	.
sfc	0.4736189	0.403396	.	0.48



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ASDL ***Aerospace Systems Design La***

Enabling Prototype Tools

Implementation and understanding of the methodology is enhanced through two prototype interface tools

-Allows the customer/warfighter to play "what if" games

-Increases customer/warfighter understanding of interrelationships

-Decreases dependence on specific software tools

-Increases portability

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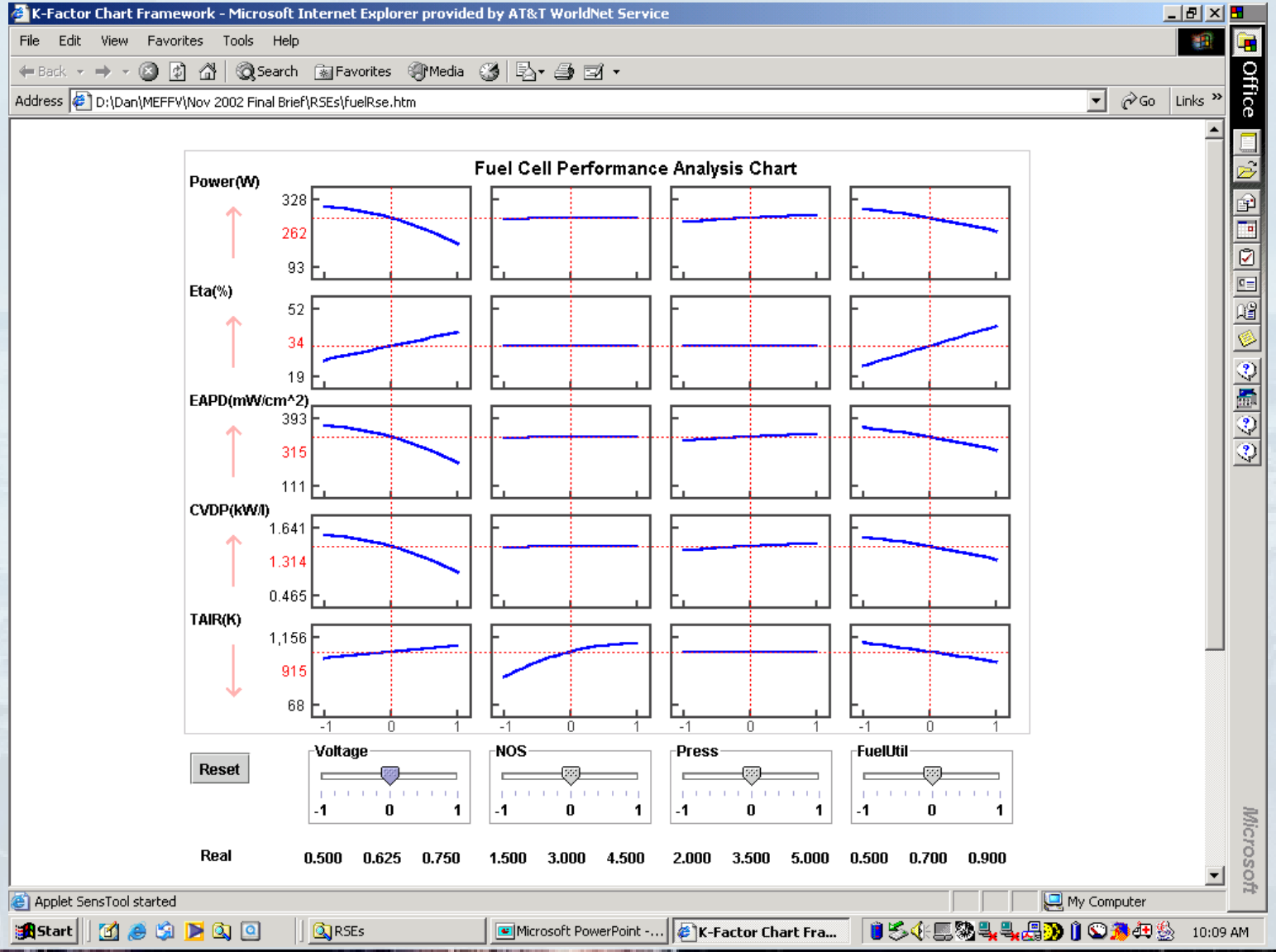
Web-Enabled Analysis/Decision-Making



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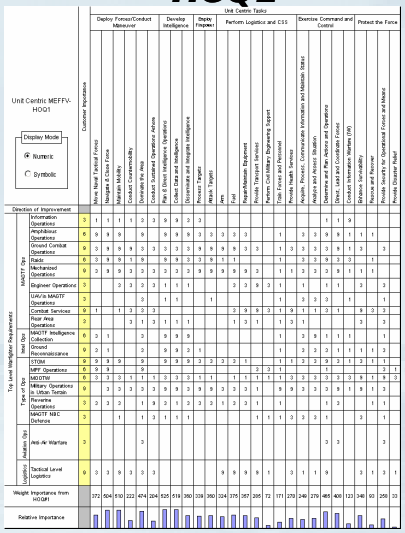
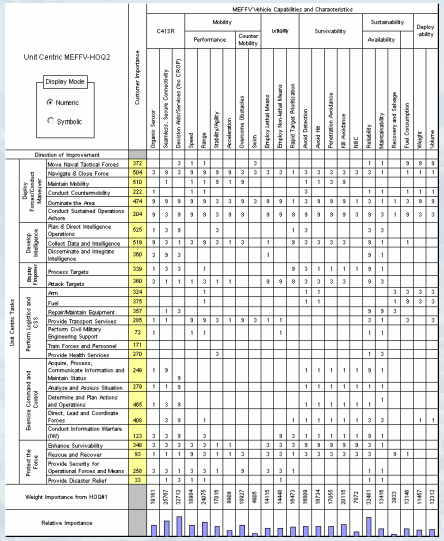
Aerospace Systems Design La

Prototype Decision Making Tool

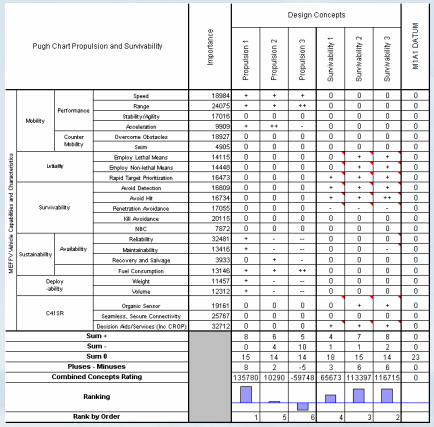
HOQ1



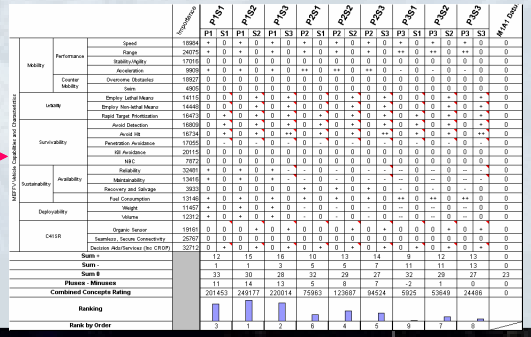
HOQ2



Pugh1



Pugh2



Created in Microsoft Excel

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Reprise- Our Mission, Our Progress

- ***"Start from the Start"***
  - QFD Process ("the pain")
  - Ranked set of customer requirements, leading to criteria for technology concept evaluations ("the gain, part 1")
  - An established, "living" tool for continued connection between customer (Marines/MEFFV PO) and S&T efforts ("the gain, part 2")
- ***"MEFFV Looking for a Technology Focus"***
  - Focused, technical survey and analysis of propulsion and survivability areas; 9 concepts created, evaluated, and compared
- ***"Ultimately, MEFFV needs a Resource Allocation Capability"***
  - Qualitative Tool Developed and Exercised for Results and Insight

Qualitative elements of future Modeling & Simulation

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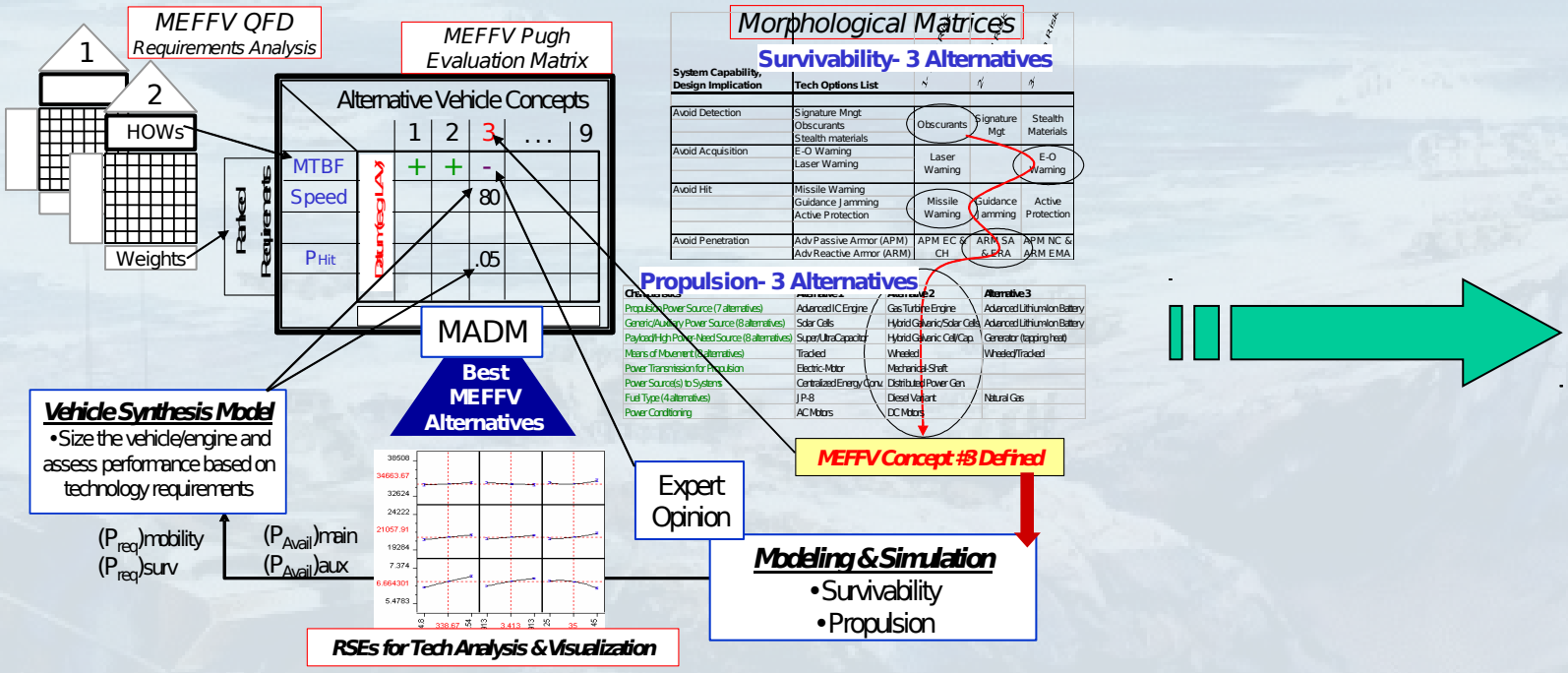
Recommendations for Future Work

The previous slides illustrate the method and progress that completed the contractual work. Recommendations for methodology expansion for the continuation of the project can be found in the next few slides.



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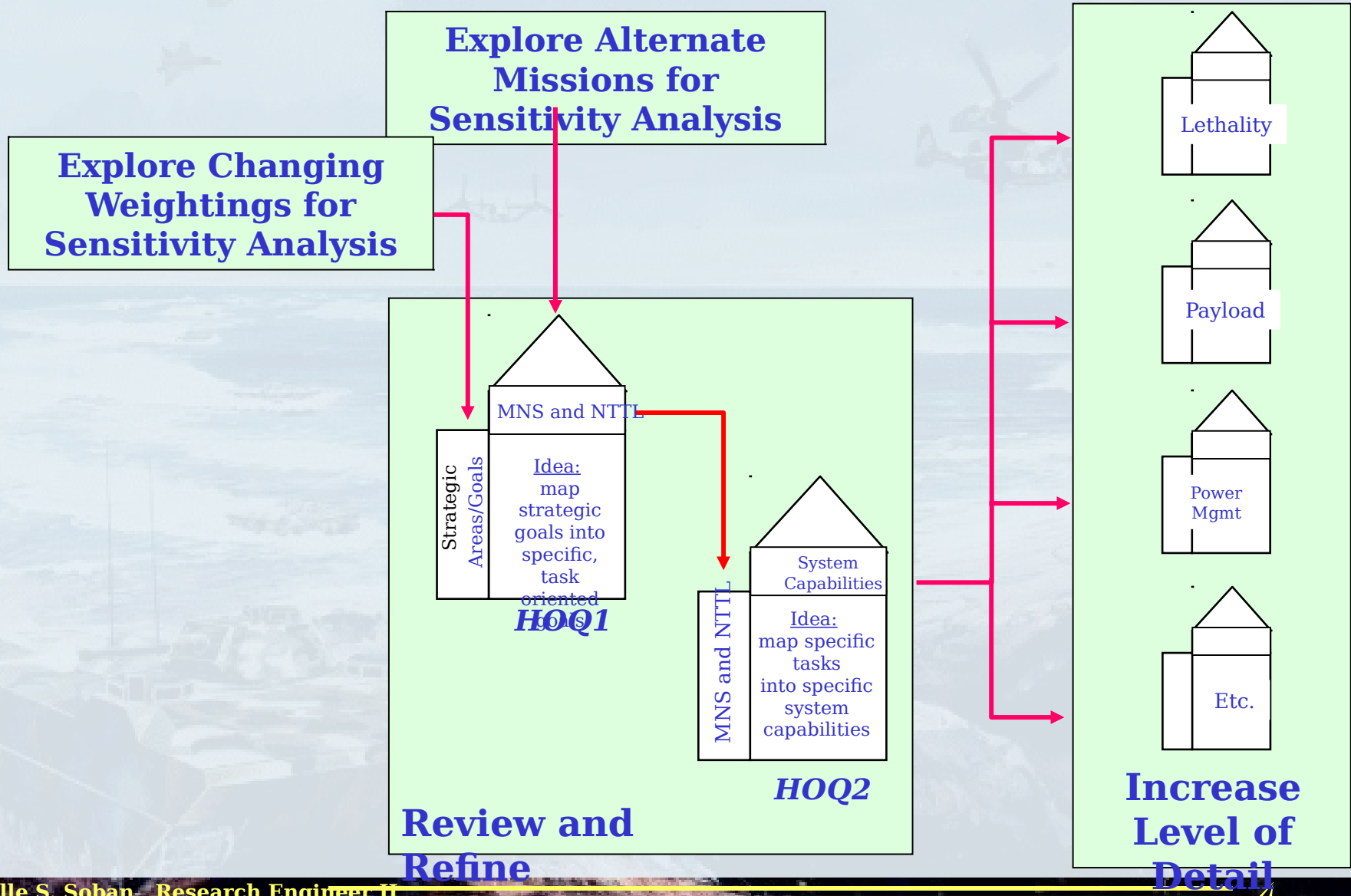
Future Work-QFD Task



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Future Work-Morphological Matrix Task

Create New Morphological Matrices Based on QFD Analysis

	P1S1	P2S2	P3S1	P2S2	P3S3	...
Speed	+	-	0	+	-	
Range	-	-	+	+	+	
Volume	++	+	+	0	0	
Weight	-				-	
Reliability	-				-	
NBC	+				-	
Swim	-				+	
Avoid Hit	+	-	0	-	0	
...						
...						

Lethality

	P1S1	P2S2	P3S1	P2S2	P3S3	...
Speed	+	-	0	+	-	
Range	-	-	+	+	+	
Volume	++	+	+	0	0	
Weight	-				+	
Reliability	-				-	
NBC	+				-	
Swim	-				+	
Avoid Hit	+	-	0	-	0	
...						
...						

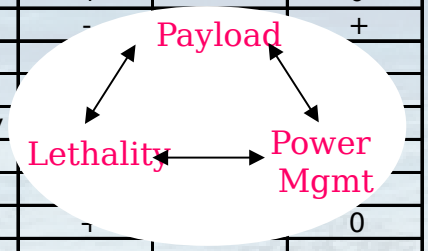
Payload

	P1S1	P2S2	P3S1	P2S2	P3S3	...
Speed	+	-	0	+	-	
Range	-	-	+	+	+	
Volume	++	+	+	0	0	
Weight						
Reliability						
NBC						
Swim						
Avoid Hit	+	-	0	-	0	
...						
...						

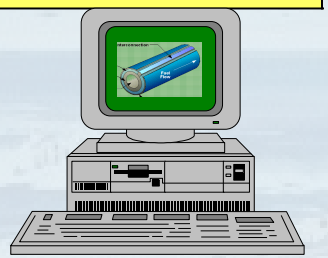
Power Mgmt

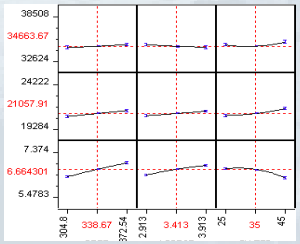
Create "Master Morphs" to Study Interactions

	System 1	System2	System3
Speed	+	-	0
Range	-		+
Volume			
Weight			
Reliability			
NBC			
Swim			
Avoid Hit			0
...			



Modeling and Simulation of Identified Systems





Develop Methods for Interactions of Disparate Systems

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Future Work-Unified Tradeoff Environment (UTE)

Employ further Technology Area Modeling & Simulation and vehicle synthesis tools to create a visual, interactive environment for trade-offs and "What-If" studies

Desirement (D) or Constraint (C)

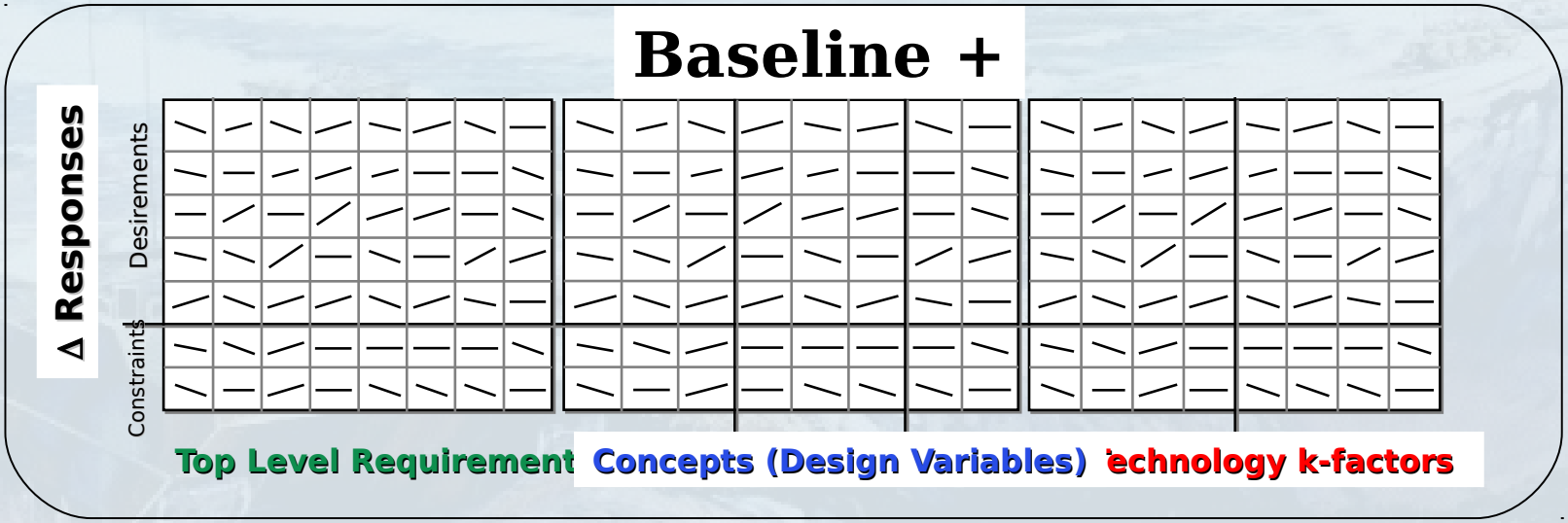
Top-Level requirements related to the mission

Design and Economic Variables

Technology k-factors (related to product and/or process)

Response = fcn (Requirements, Concepts, Technologies)

$$D_i = f(R, DV, k_T), \quad C_i = g(R, DV, k_T)$$



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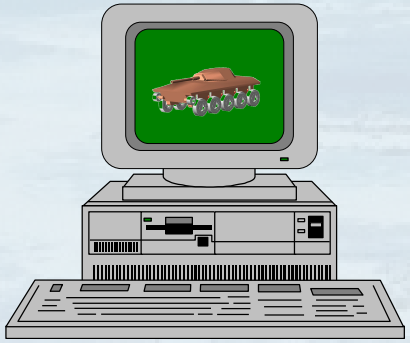
Future Work- Vehicle Synthesis Tool

In order to adequately assess impacts and make key design decisions, a ***vehicle synthesis capability must exist***

-Physics based



-Capable of modeling discipline and technology integrations

-Not vehicle specific

-Can combine existing technology and subsystem models

★ -Next, necessary step in Process Roadmap

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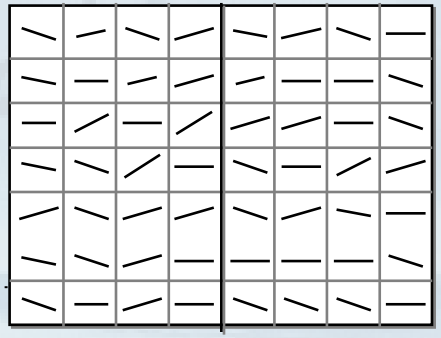
MEFFV- Synthesis Model Enables UTE

Fundamentally, 3 dynamics affect MEFFV:

- Requirements
- Design Factors (Shape, etc)
- Technologies

$(P_{req})_{mobility}$

$(P_{req})_{surv}$



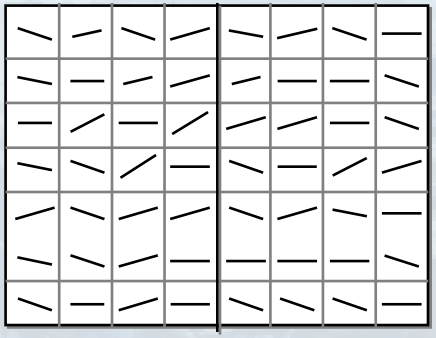
Concepts (Design Variables)

Vehicle Synthesis Model

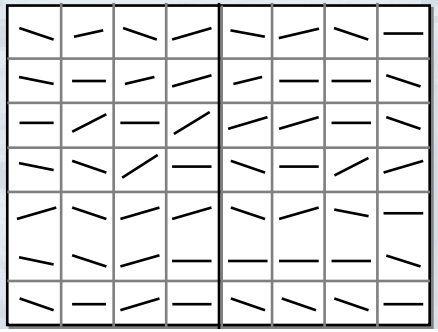
- Engine- POWER BALANCE
- Vehicle- FUEL BALANCE
- Convergence

$(P_{Avail})_{main}$

$(P_{Avail})_{aux}$



Requirements (e.g. Range, Speed)



Technology k-factors (e.g. weight factors, sfc factor)

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Future Work- System of Systems Effectiveness Mapping

MoEs

Campaign Level

Vehicle Level Measures of Performance (MOPs)

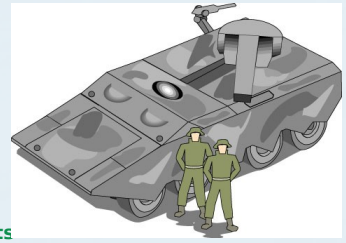
Create links via synthesis and modeling tools that allow mappings of system (campaign) level Measures of Effectiveness to sub-system technology design variables.

MoPs

Responses Metrics/Objectives

Constraints

Vehicle Level



Technology k-factors

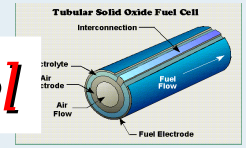
Vehicle Design Factors

Top Level Requirements

Technology metrics become variables for next level

Technology Metrics

Subsystem Level



Design Variables

Fuel

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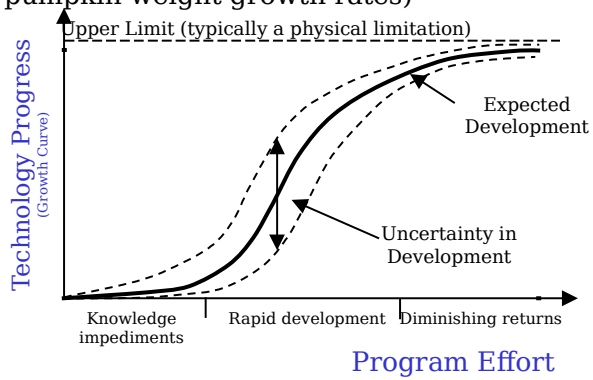
Future Work- Assess Technology Uncertainty

As defined by NASA, *the major milestones* achieved from concept formulation to widespread application have been characterized into a metric known as the technology readiness level (TRL)

Technology Readiness Levels

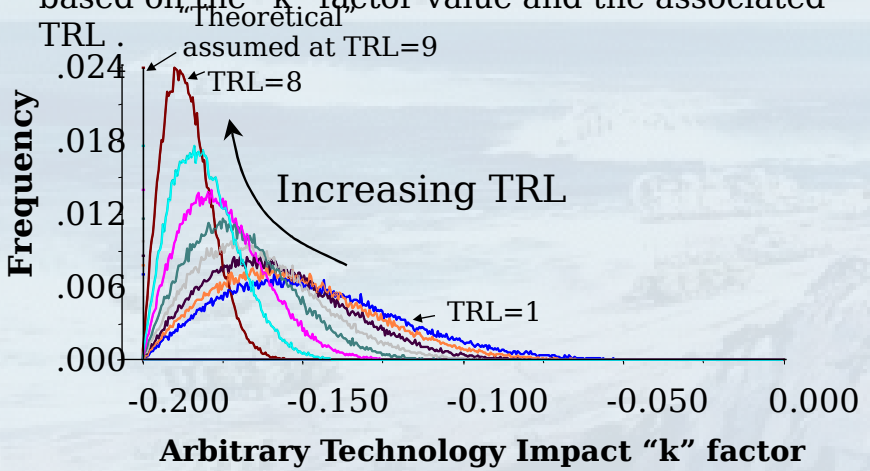
Level	Readiness Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated (candidate selected)
3	Analytical and experimental critical function or characteristic proof of concept or completed design
4	Component and/or application formulated
5	Component (or breadboard) verification in a relevant environment
6	System/subsystem (configuration) model or prototype demonstrated/validated in relevant environment
7	System prototype demonstrated in flight
8	Actual system completed and flight qualified through test and demonstration
9	Actual system flight proven on operational vehicle

Method of Analogy: Assumes that a technology development program follows the same growth curve as a biological system (e.g. yeast cells, embryos, and pumpkin weight growth rates)



Bounding the Uncertainty:

- Assume the technological uncertainty diminishes with increasing TRL and shifts towards the assumed impact at a TRL of 9 based on the "method of analogy"
- Each technology can be simulated by this method by defining each element of a technology impact vector ("k" factors) as a Weibull distribution based on the "k" factor value and the associated TRL .



Technological uncertainty is a function of:

- *knowledge available*
- *schedule*
- *budget*
- *available resources (manpower, facilities, etc.)*
- *manufacturing*
- *methods and tools used to analyze and design*
- *integration difficulties*
- *physical limitations and contradictions*
- *etc.*

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